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16. Abstract

Investigation of the effect of high altitudes upon cutaneous circulation and thermal exchange is made. It is concluded that at high altitudes the effects of hypoxia and hypocapnia can be dissociated.

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CUTANEOUS CIRCULATION AND THERMAL EXCHANGE AT ALTITUDE (3800 m)

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I. Introduction

During a series of investigations of circulatory changes induced by altitude in man, a reduction in blood flow and volume was noted with respect to values obtained at sea level. This difference disappeared if the hypocapnia was corrected (Durand and Martineaud, 1971). This finding has led us to consider possible consequences for thermal exchange at altitude in resting males undergoing an external and/or internal thermal load (muscular exercise). /A247**

II. Techniques

The experiments were performed at the Institut bolivien de biologie d'altitude (Bolivian Institute of High Altitude Biology) at La Paz (3800 m, mean barometric pressure P_B = 493 mm Hg) in two

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successive trips. They were conducted on 11 subjects. Of these, six were born and lived permanently between 3800 and 5200 m, while five came from sea level and had lived at altitude for three weeks. These last subjects had previously been observed under the same conditions, except for altitude, in Paris (altitude 50 m). /A248

The measures were taken in an isolated enclosure, at rest and during muscular work on an ergometric bicycle at three powers: 60, 80, and 100 W. Each exercise period lasted 25 minutes.

Each series of experiments was performed at two different ambient temperatures, 20° C and 34° C. In each case, at altitude and at sea level, the partial pressure of water vapor was between 8 and 9 mm Hg, allowing complete evaporation of perspiration. The experiments were selected in random order.

In six subjects (four natives and two visitors), another set of experiments was carried out at an ambient temperature of 27° C. The subject breathed a mixture containing 5 percent CO_2 (alveolar pressure of CO_2 about 37 mm Hg).

The following data were gathered:

— open circuit consumption of oxygen (V_{O_2});
— perspiration flow by discontinuous weighing;
— central temperature, esophageal and rectal (T_{re});
— cutaneous temperature at 10 different points;
— environmental temperature (overall, wall, dry, humidity);
— heart rate;
— plasma concentration of lactic acid.

The calorimetric data were calculated by using the following coefficients:

— relationship between core and total mass = 0.8 (the same relation was used in every case);

— coefficient of radiation-convection (according to Colin et al., 1966) = 6.6 $W/m^2/°C$ at sea level, and 6.1 $W/m^2/°C$ at altitude;

— equivalent energy of oxygen = 20.3 J/ml.

The mean cutaneous temperature ($\overline{T}_{sk}$) was calculated by using the weighting of J. D. Hardy and E. F. DuBois (Hardy and DuBois, 1938).

III. Results

At rest: The subjects originally from low altitudes equilibriated their thermal balance different at sea level than at altitude. $\overline{T}_{sk}$ had the same value under these two conditions, but T_{re} was higher at altitude. The reduction of physiological conductivity, linked to the reduction in cutaneous flow, is compensated by the increase in the difference between artero-venous cutaneous temperature, which is approximately equivalent to the difference (T_{re} - $\overline{T}_{sk}$). /A250

In the residents, the difference (T_{re} - $\overline{T}_{sk}$) is larger than in the recently moved subjects, both because T_{re} is higher, and also because $\overline{T}_{sk}$ is lower in these subjects. This difference corresponds to the higher hemodynamic cutaneous resistance.

During exercise: At the 25th minute, the stationary thermal state is not reached. Heat is still being stored, while V_{O_2} is apparently stable from the 5th minute (Figure 1). Visitors and residents have an identical overall energy output, which is the same as at sea level. The comparison of energy production determined from V_{O_2} and from the sum of different elements of energy balance, calculated independently, are in excellent accord. This justified, a posteriori, the validity of the coefficients used (Figure 2).

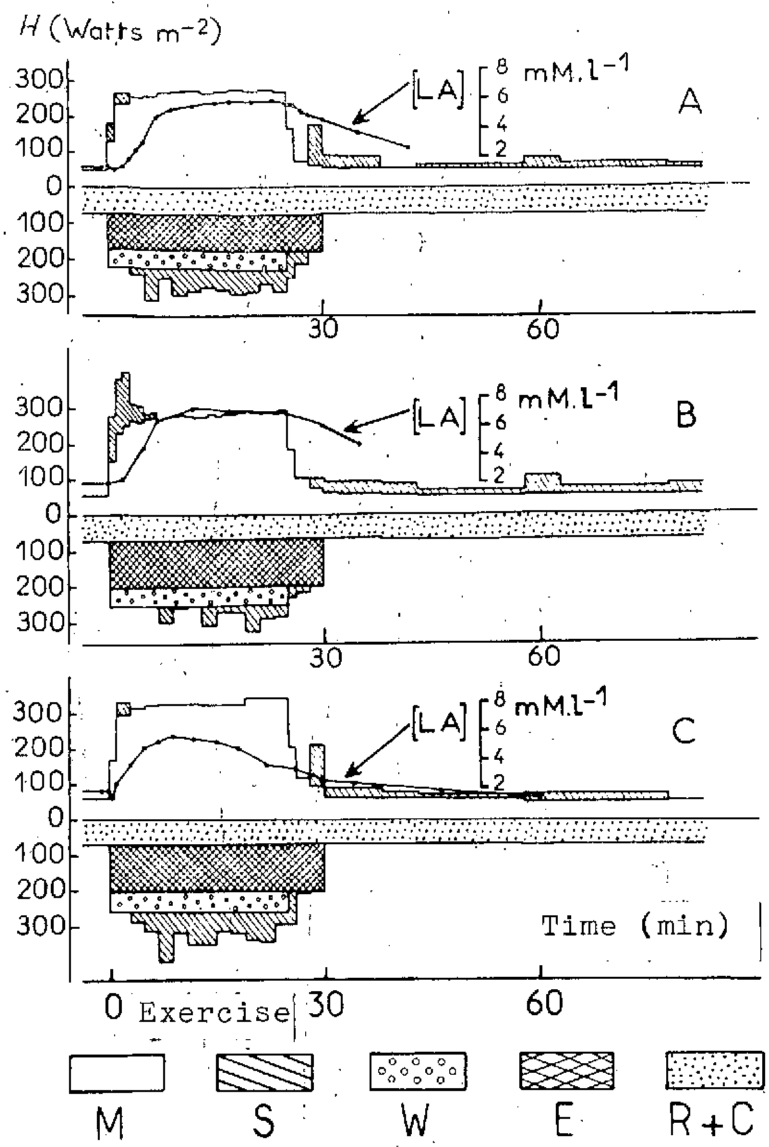

Figure 1. Energy output (Watts · m^2) as a function of time, at rest, during muscular exercise, and during the recovery phase. On the positive half are shown aerobic production (M) and storage (S). The venous concentration of lactic acid is superimposed. On the negative half are shown loss of heat by radiation-convection (R + C), evaporation (E), heat storage (S), and production of mechanical energy (W). In A, subjects from lower altitudes studied at 50 m; in B, the same subjects at 3800 m; in C, subjects from 4100 m studied at 3800 m

In the visitors, T_{re} increases more at altitude than at sea level, and $\overline{T}_{sk}$ dimishes with respect to resting values while changing very little at low elevations. Because of cooling on the outside, heat storage and losses by radiation and convection are smaller. On the other hand, cutaneous and respiratory evaporation flow is increased.

In the residents, by comparison with the resting state, T_{re} increases, but $\overline{T}_{sk}$ remains at its appropriate value, so that heat storage appears more pronounced than in the visitors.

<u>During CO_2 inhalation</u>: Correction of hypocapnia at altitude produces a subjective sensation of cold such that it is not possible to conduct prolonged observations at an ambient temperature less than 27° C.

During exercise, with respect to rest, maintenance of the temperatures $\overline{T}_{sk}$ and T_{re} is objectively observed. In a normal environment under the same conditions, $\overline{T}_{sk}$ and T_{re} increases. With respect to rest, evaporation loss increases, and losses by radiation or convection change only slightly, or not at all. These results are similar to those recently published by Y. Houdas (Houdas et al., 1973), and surpass by far the changes observed at sea level under the same conditions.

IV. Conclusions

The reduction in cutaneous blood flow at rest and during exercise in resident and newly moved subjects at altitude reduces the possibility for heat transport from the core to the periphery. This reduction in physiological conductance is compensated by the increase in the difference in arterio-venous cutaneous temperatures. The latter is itself due to the increase

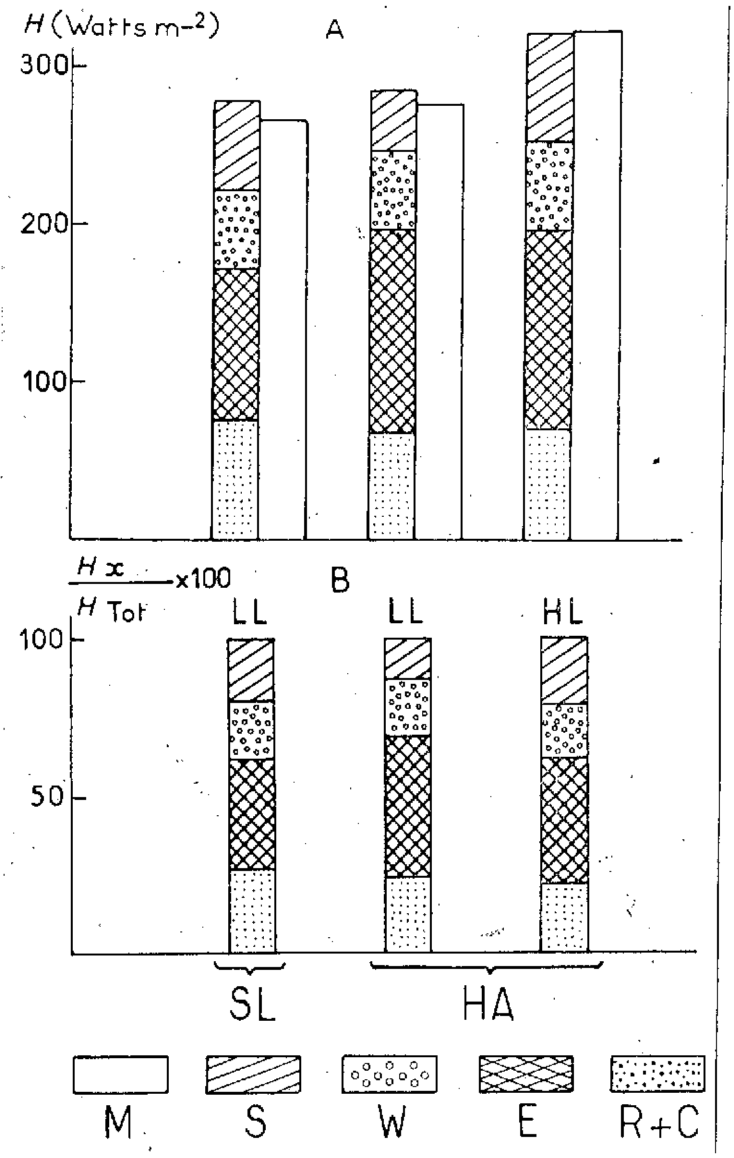

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Figure 2. Energy balance (H) obtained between the 15th and 25th minutes of exercise on the ergometric bicycle:

A — Absolute values of energy production (M), of energy lost by radiation and convection (R+C), evaporation (E), and by mechanical energy, about 53 watts · m^2 (W), and stored energy (S). The first column corresponds to subjects at sea level (LL) studied at 50 m altitude (SL); the second — to the same subjects observed at 3800 m (HA), and the third — residents at altitude (HL)

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Figure 2 (continued). in their environment of origin. B — percentage of different elements of the energy balance

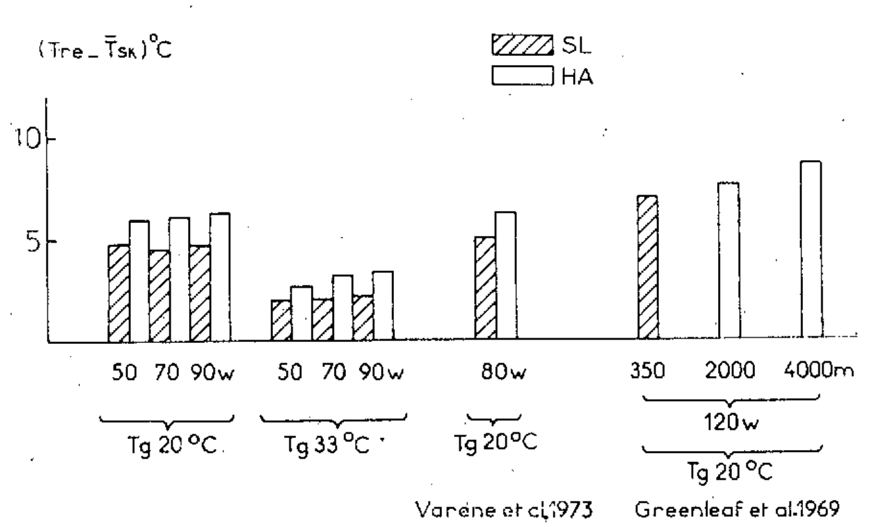

Figure 3. Differences in central temperature (T_{re}) and peripheral temperature ($\overline{T}_{sk}$) for different values of ambient temperature (T_g), and for different powers of exercise in watts (W), at sea level (SL) and at 3800 m (HA). The results coming from finding by other writers are indicated

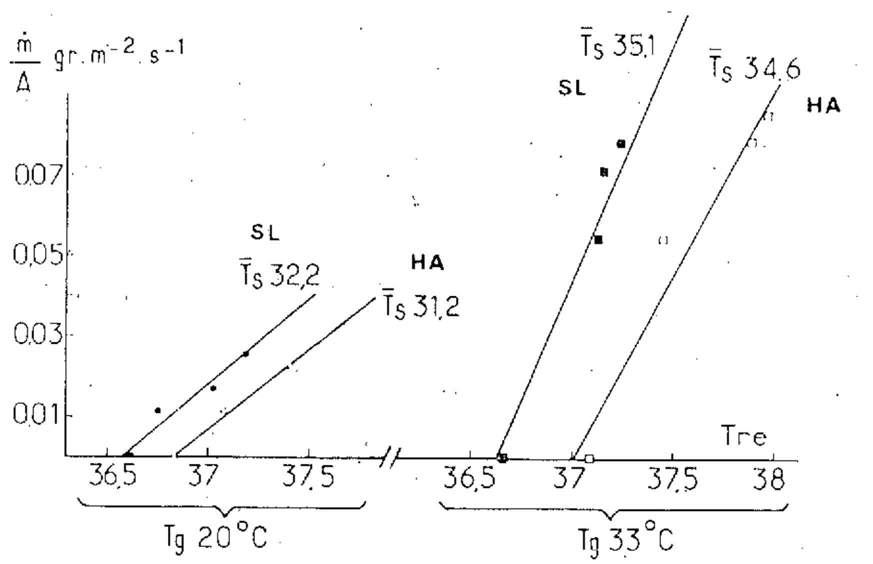

Figure 4. Sweat flow, m (g · m^{-2} · s^{-1}) as a function of rectal temperature T_{re} (°C) for two values of ambient temperature T_g, 20 and 33° C.

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Figure 4 (continued). Observations at sea level — (SL); observations at altitude — (HA). The mean cutaneous temperature $\overline{T}_{sk}$ (°C) is given close to the corresponding line

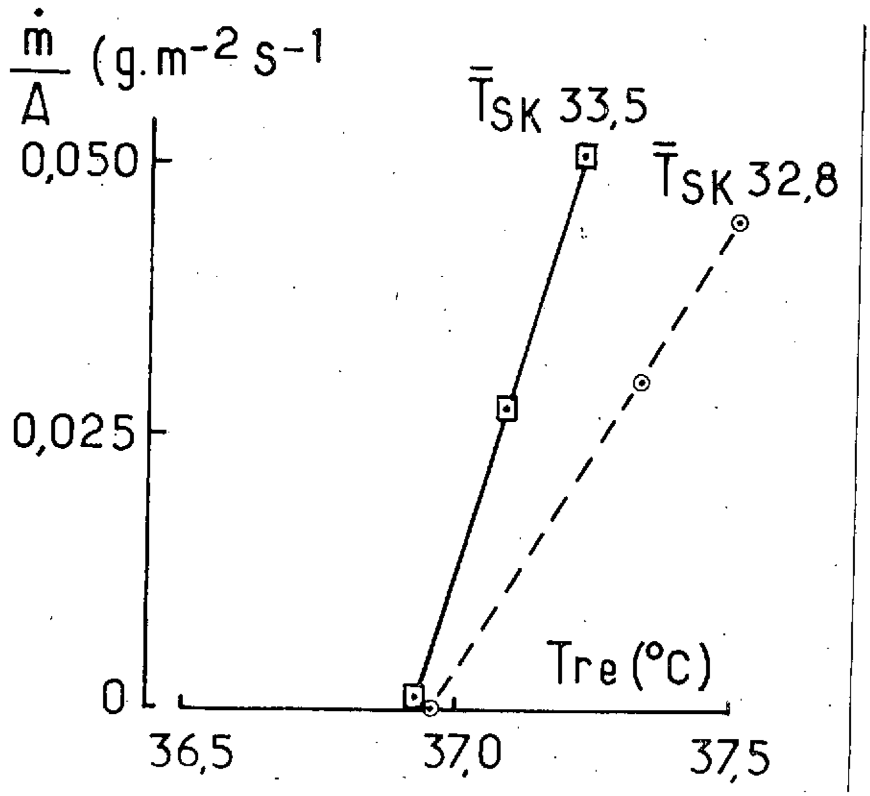

Figure 5. Sweat flow, $\frac{\dot{m}}{A}$ (g.m^{-2}.s^{-1}), as a function of rectal temperature Tre (°C), at rest and during exercise, at 3800 m in subjects breathing ambient air (⊙), and in subjects inhaling a mixture containing a fraction of CO_2 to elevate the partial pressure of alveolar CO_2 to about 37 mm Hg (⊡). The mean cutaneous temperature, $\overline{T}_{sk}$ (°C), is indicated near the corresponding line

in core temperature and to the reduction in superficial temperature (Figure 3). The latter keeps pace with the change in evaporation flow.

These findings are also apparent in the data obtained from compression caissons by J. E. Greenleaf (Greenleaf et al., 1969), or at natural altitude by P. Varene (Varene et al., 1973).

During acclimation to altitude in the newly moved subjects, sweat flow as a function of rectal temperature (Figure 4) apparently does not change slope. Only the origin on the ordinate is shifted. In the natives, the scatter of the results precludes interpretation.

The re-establishment of a P_{ACO_2}, close to that of sea level, reduces cutaneous hemodynamic resistance and increases transport and loss of heat. The evaporatory loss as a function of core tempera- /A253
ture (Figure 5) has the same value on the abscissa at the origin, but the slope is greater with CO_2 than with air.

Several hypotheses can explain these findings, and the data given here do not allow selection among these. However, according to our experiments, it appears that at altitude, the effects of hypoxia and hypocapnia can be dissociated. With respect to the preceding relationship, hypoxia acts on the level of confinement, hypocapnia — on the gain.

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